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DEVELOPMENT OF HIGH DAMPING FERROUS SHAPE MEMORY ALLOYS

FIRST ANNUAL REPORT - FY 1990
CONTRACT NUMBER N00014-90-C-0076

by

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INTRODUCTION

Alloys which exhibit high damping have potential in applications for noise and vibration controls. The damping mechanism in these alloys is generally related to the hysteretic effect of microstructural interfacial motions. For example, damping in Fe-Cr-Al alloys is due to the stress induced motion of ferromagnetic domain boundaries. Shape memory alloys, such as Cu-Al-Ni, Cu-Zn-Al and NiTi, also exhibit high damping due to the motion of martensitic interfaces which can be driven by the excitation stress. However, the mechanical properties of shape memory alloys are highly temperature dependent in the range of the martensitic transformation. The modulus of these alloys is also quite low in the martensitic state making them less suitable for structural applications.

The shape memory effect has been observed in ferrous alloys including Fe-Mn, Fe-Ni and Fe-Al based alloys as well as Fe-Pt and Fe-Pd alloys. These alloys, exhibiting a less perfect shape memory effect than do conventional shape memory alloys, have certain characteristics, such as higher modulus, better thermal stability and potentially lower cost, which could make them more suitable for structural damping applications.

Memry Corp., in collaboration with the University of Illinois, is working on a three-year program (1990-1992), under contract to The Office of Naval Research, to study the fundamental damping mechanism in ferrous alloys with particular reference to the Fe-Ni system. The objective is to understand the effect of thermoelastic transformations, which often are associated with thin plate martensite morphology, and non-thermoelastic transformation on damping and the factors, such as precipitation, matrix deformation and martensite tetragonality, which may control the martensitic transformation characteristic. This knowledge will then be used as a guideline for the development of high modulus, high damping ferrous alloys.

Initial emphasis was placed on Fe-Ni system because it has been shown in the literature that thermoelastic transformation can be obtained in Fe-Ni-Ti-Co alloys by manipulating the annealing process. The system is thus ideal for studying the factors which influence the thin plate morphology and thermoelasticity. However, it was felt that in the early stage of the research both Fe-Mn and Fe-Al-C systems ought to be included for the following reasons;

- a. The martensitic transformation in both systems is typically non-thermoelastic.
- b. Fe-Mn martensites are HCP ϵ martensites with no fine structure of lattice invariant shear.
- c. The tetragonality of Fe-Al-C martensites is very high in comparison to that of Fe-Ni martensites.

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The systems selected for the program are the following;

<u>Alloy</u>	<u>Martensite Structure</u>
1. Fe-Mn-Si-X	HCP ϵ (Non-thermoelastic)
2. Fe-Ni-Ti-Co	BCT α' (Thermoelastic and Non-thermoelastic)
3. Fe-Al-C	BCT α' (Non-thermoelastic)

WORK PERFORMED IN FY 1990

The work completed in FY 1990 focused primarily on Fe-Mn-Si-X systems, which includes design of compositions, transformation characterization, mechanical testing and preliminary damping testing.

1. Alloy Compositions

Eight compositions of Fe-Mn-Si based alloys, listed in Table 1, have been studied. Since good shape memory effect (SME) generally implies reversible martensite interface motion, and hence good damping capacity, shape memory effect is used as a guideline for high damping alloys. The basic approaches for the selection of these compositions are

- To minimize plastic deformation by increasing the yield strength of the austenite by solution hardening (Si, Al, Cr) and precipitation hardening (Ni and Al).
- To promote the glissile nature of martensite interfaces by reducing the stacking fault energy (Si, Mn and Co).
- Setting the Neel temperature, T_n , to either around or below the martensitic transformation temperature (Co).

Table 1. Chemical Compositions (wt.%) of the Alloys.

Alloy	Fe	Mn	Si	Cr	Ni	Co	Al	SME
1	bal.	30.0	7.0	5.0	2.5			fair
2	bal.	30.0	5.0			4.0		good
3	bal.	29.0	5.5	4.5	2.0	3.5		good
4	bal.	30.0	6.0				2.0	fair
5	bal.	31.0	2.0				4.0	poor
6	bal.	27.0	6.0				5.0	---
7	bal.	25.0	4.0				2.0	fair
8	bal.	13.8	6.0	8.4	5.0			good

2. Experimental Procedures

The alloys were all solution heat treated at 1027°C for 1 hour, followed by a water quench. Martensitic transformations were characterized using electrical resistivity measurement, differential scanning calorimetry (DSC) and dilatometry. Magnetic

transition was analyzed by susceptibility measurement. The shape memory effect was characterized by mechanical bending tests.

3. Results and Discussion

Among the alloys studied, alloys 2, 3 and 8 were found to exhibit better shape memory effect than the others. Alloys 3 and 8 were selected for further detailed studies in order to examine the effects of Co and T_n temperature.

3.1. Néel Temperature

The magnetic susceptibility of alloys 3 and 8 is plotted versus temperature in Figure 1. The curves are typical of a paramagnetic-to-antiferromagnetic transition. Neel temperature, T_n, measured from the peak of the curves is -43C and -183C for alloy 3 and 8, respectively.

3.2. Transformation Temperatures

The resistivity of alloy 3 decreases with temperature and reaches a minimum at the Néel temperature. Further cooling causes an increase in resistivity due to antiferromagnetic ordering (Figure 2-1). Although the martensitic transformation temperature is obscure due to the magnetic transition, a decrease of resistivity during heating in association with the reverse martensitic transformation is consistently observed between 90C (A_s) and 135C (A_f) in curve (a) of athermal martensite and in curve (c) of stress induced martensite. The reverse transformation of stress induced martensite, as evident from resistivity increase with deformation at 20C in curve (b), is less well defined probably due to a more severe permanent deformation when the alloy is deformed at temperatures well above the M_s temperature.

Because the magnetic transition of alloy 8 is well below the martensitic transformation, the resistivity changes associated with the transformation are more distinct than those of alloy 3, as shown in Figure 2-2. The transformation temperatures are determined as follows; M_s=-20C, M_f=-90, A_s=110C, A_f=130C for athermal martensite (curve a) as well as stress induced martensite which was induced at 20C (curve b) and -196C (curve c).

The transformation temperatures of quenched alloy 8 determined by DSC (Figure 3) are slightly higher than those measured from the resistivity change. These temperatures are M_s=34C, M_f=12C, A_s=128C, A_f=153C. The discrepancy needs to be further clarified.

The transformation of alloy 8 exhibits several ageing effects. First, the transformation temperatures decrease with ageing time at 200C and above. An example is shown in Figure 4. The transformation enthalpy (shown in Figure 5) also increases with ageing in this temperature range.

3.3. Shape Memory Effect

Pseudoelastic strain (PE), SME strain and residual plastic strain (RS), measured by bending tests, are plotted in Figure 6. All three strain components of both alloy 3 and alloy 8 increase with initial bending deformation (Prestrain). While little difference is observed for alloy 8, bending at -196C (77K) greatly improves the SME recovery for alloy 3 than bending at ambient temperature (300K). For alloy 3, a maximum SME strain of 5% can be obtained, and 4% for alloy 8.

Although the Ms and Mf temperatures of alloy 3 were not determined, the effect seems to imply that the martensitic transformation is depressed to lower temperatures due to the antiferromagnetic transition. Antiferromagnetic ordering, on the other hand, may be beneficial to SME since the maximum SME strain of alloy 3 is higher than that of alloy 8.

3.4. Mechanical Testing

Preliminary testing of alloy 8 indicates a two stage yield stress-strain curve, as in Figure 7, which is typical of shape memory alloys. The first yield is due to a realignment of the martensite crystal orientation, since the sample was tested in a fully martensitic state, and the second yielding is truly an onset of the plastic deformation of the martensite. The alloy also shows an excellent ductility of 65% before failure. The martensite yield strength measured from the curve is 396 Mpa and the tensile strength is 832 Mpa.

3.5. Damping Test

The damping test of alloy 8 was carried out using a Dynamic Mechanical Thermal Analyzer (DMTA) in David Taylor Naval Research Laboratory (DTNRL). A damping peak is present in the temperature range of 120-160C, in agreement with the reverse transformation temperature (Figure 8). The loss factor is strain dependent and can be increased by increasing the strain amplitude (Figure 9). This behavior is common to the damping characteristic of shape memory alloys.

4. Summary

Based on the work performed in FY 1990, the SME and damping property of Fe-Mn-Si based alloys are clearly demonstrated. The alloys exhibit good mechanical property and can be easily fabricated. A maximum SME shape recovery of 5% and a loss factor of 0.04 at 0.005 microstrain can be achieved.

WORK SCHEDULE FOR FY 1991 AND FY 1992

The study of Fe-Mn-Si based compositions will be an on-going task. Further investigations of alloys 3 and 8 will involve mechanism studies using transmission electron microscopy (TEM) and more detailed SME and mechanical characterizations. Complete damping testing is scheduled for the last three quarters of FY 1991.

Alloy preparation of Fe-Ni-Ti-Co and its characterization are to be carried out in the FY 1991. This effort is to allow the damping test to be performed in the last quarter of FY 1991 and the first half of FY 1992.

A new alloy, which may come from a modification of either Fe-Mn or Fe-Al based compositions, will be selected at the end of FY 1991 based on the SME property. Detailed characterizations and damping test are to be carried out in FY 1992.

The program schedule is summarized in Table 2.

PERSONNEL STATUS:

I. Memry Technologies, Inc.

Drs. C.Y. Lei, M.H. Wu and L.M. Schetky; program hours will be according to the budget.

II. The University of Illinois

1. Dr. J. Yang (Postdoctoral Research Associate) was with the program from January 1 to August 31, 1990. He completed most of the study on alloys 3 and 8. Two paper manuscripts are under preparation based on the results of his work.

2. Dr. J. Li (Postdoctoral Research Associate) started on the program from September 1, 1990. He will initially study Fe-Al-C alloys.

3. Ms. A. Hamers is an exchange student from Holland. Her financial support comes from the exchange program and will not be charged to the program. She will be associated with the program for one year, studying Fe-Mn-Co and Fe-Mn-Al-Co-Si alloys.

These staff members are under the supervision of Professor C.M. Wayman.

III. The University of Maryland

The initial damping test was carried out at David Taylor Naval Research Laboratory under the supervision of Ms. Cathy Wong. However, due to the strain amplitude limitation of the DMTA, an arrangement was made with Professor M. Wuttig to use his facility at the University of Maryland for future damping tests.

Professor Wuttig is currently investigating damping phenomena under separate financial support from the Office of Naval Research.

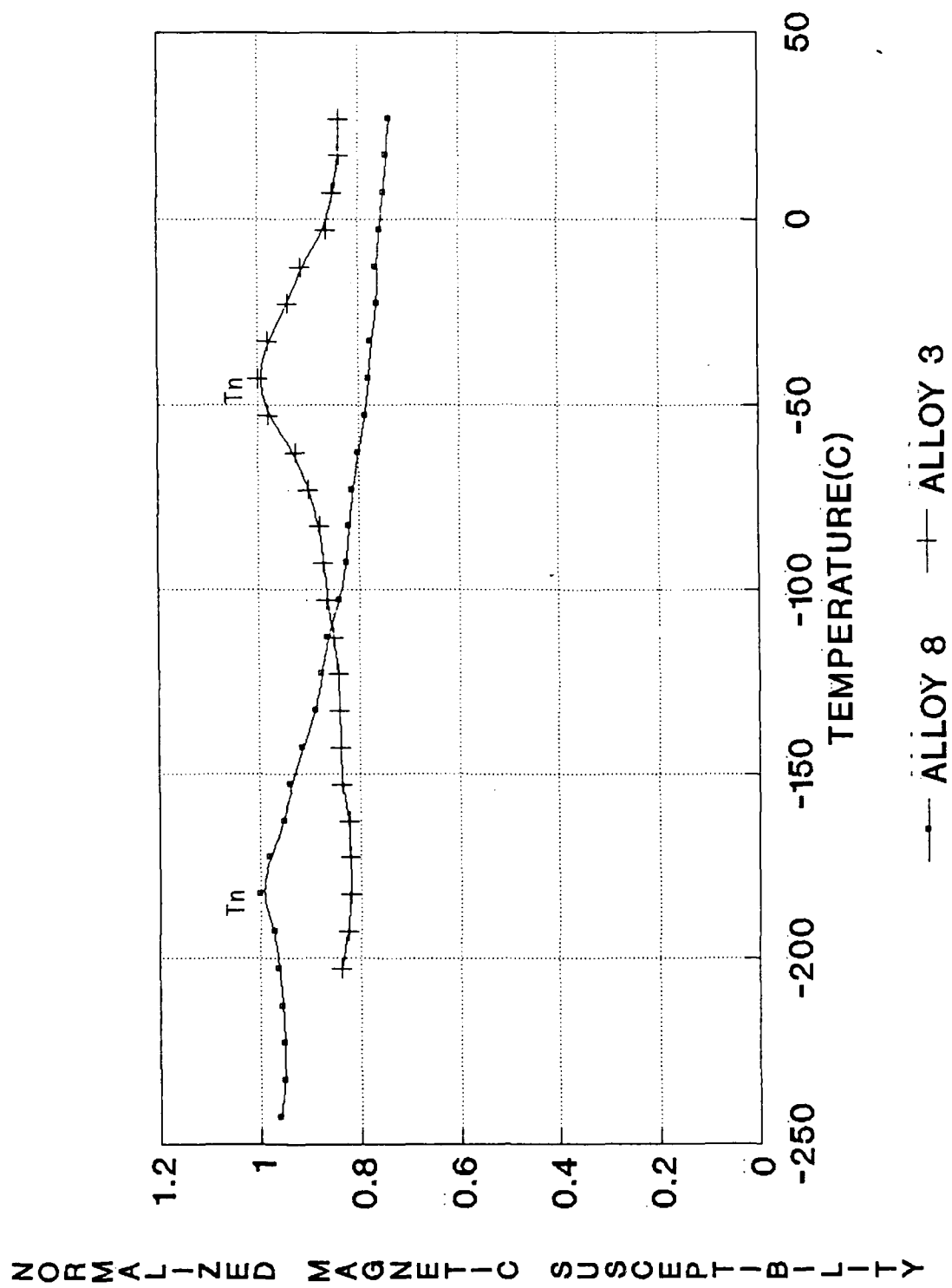


Figure 1

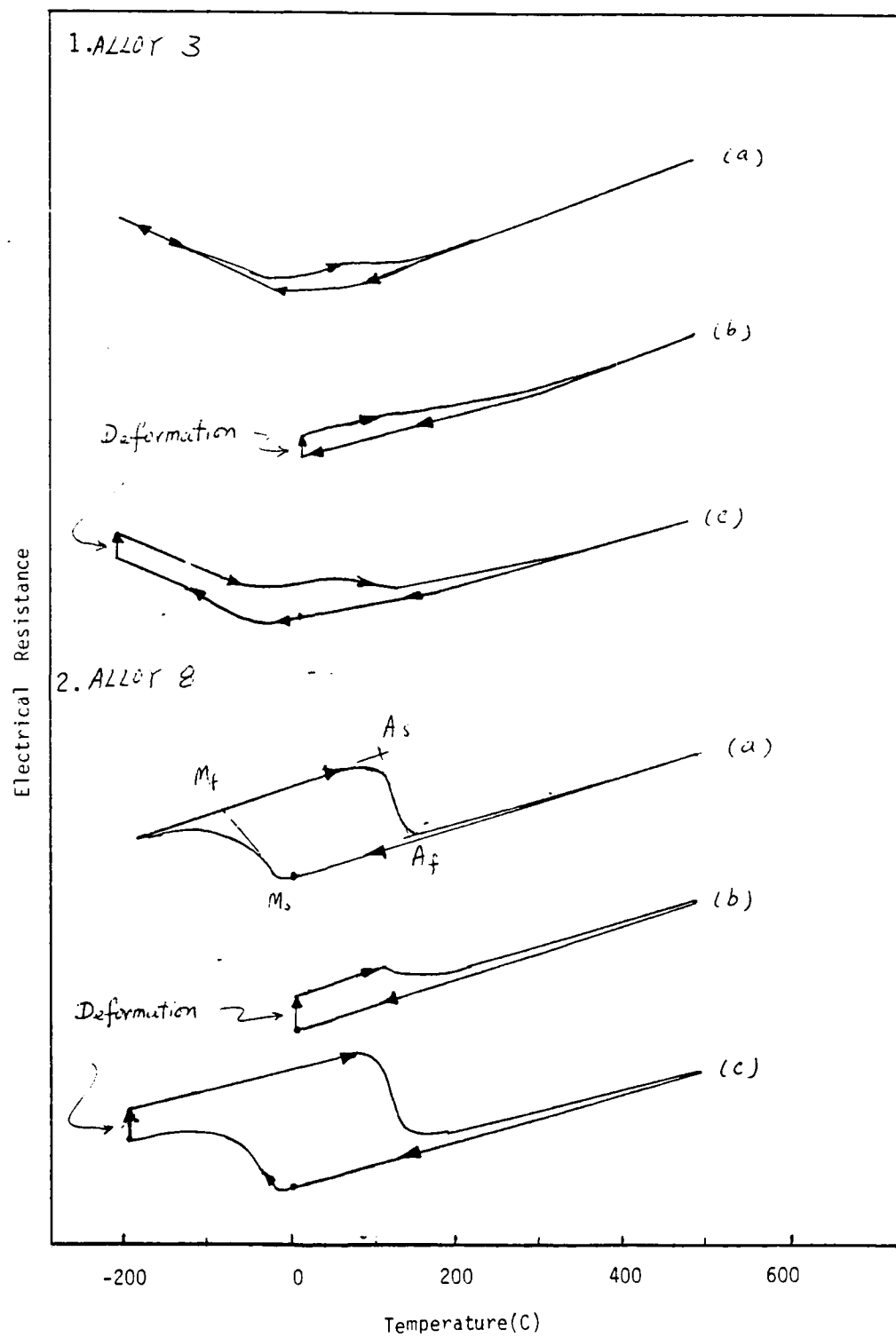


Figure 2.

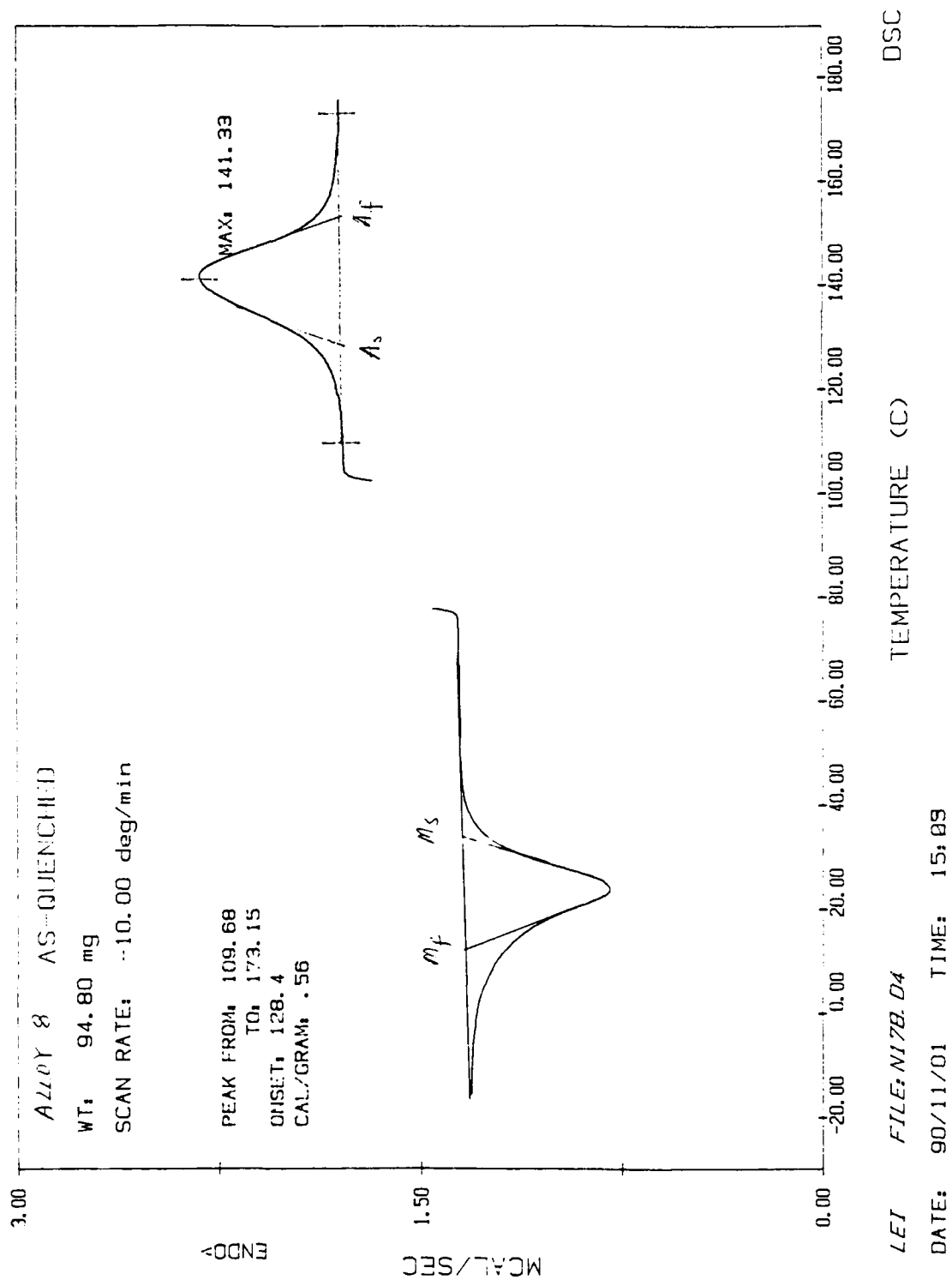


Figure 3.

FeMSCN Transformation Temperatures

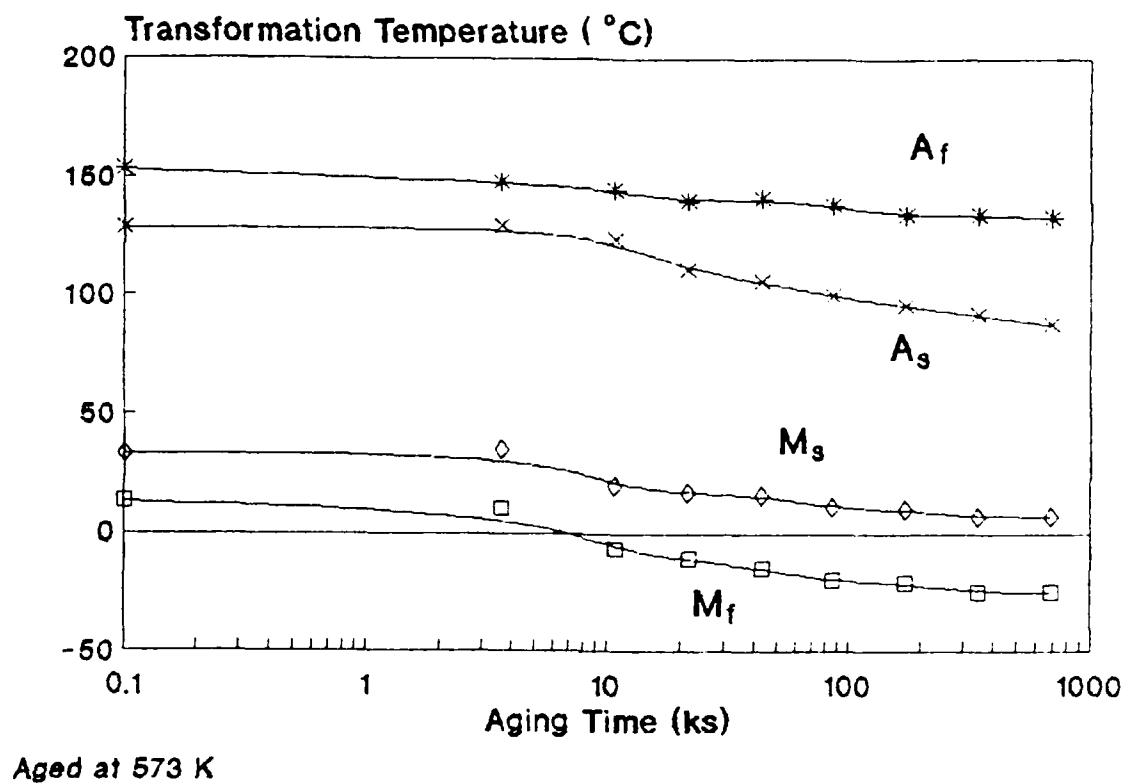
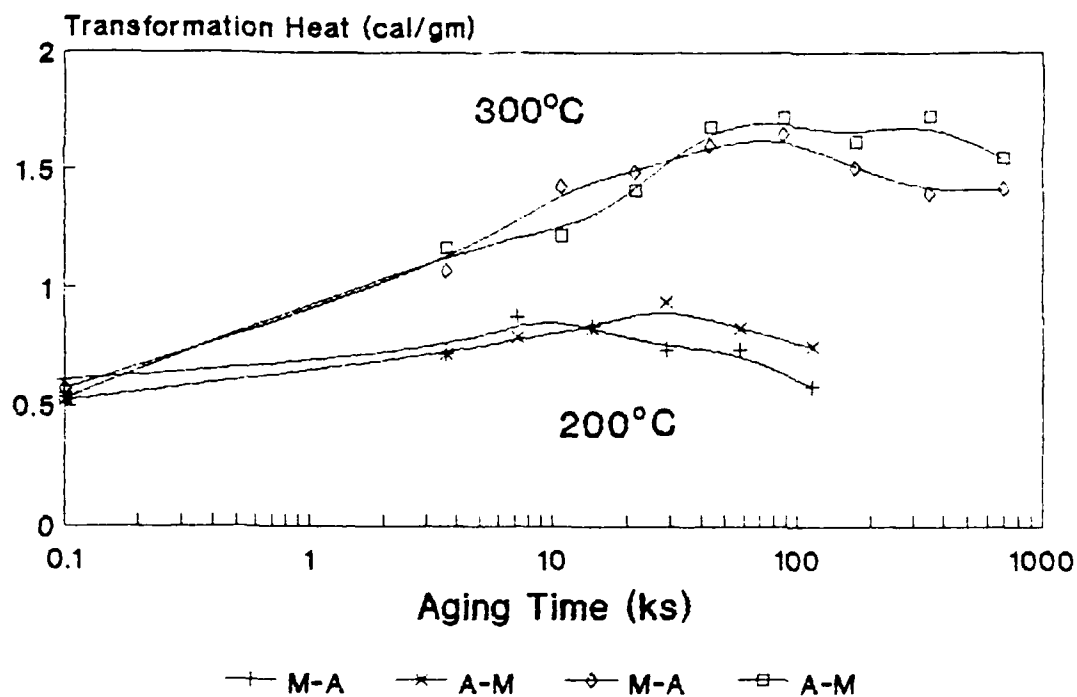


Figure 4.

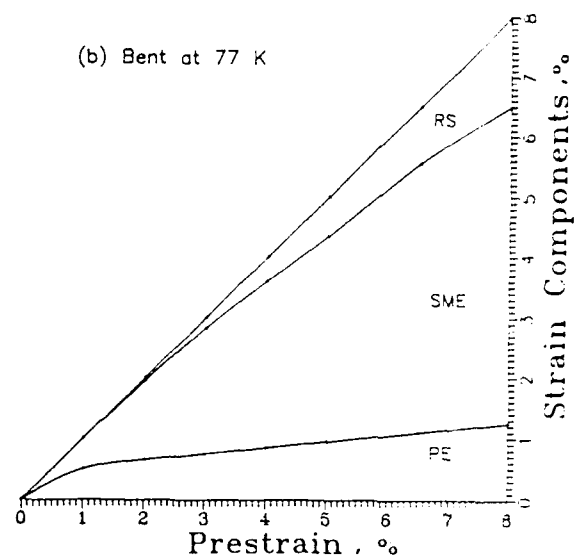
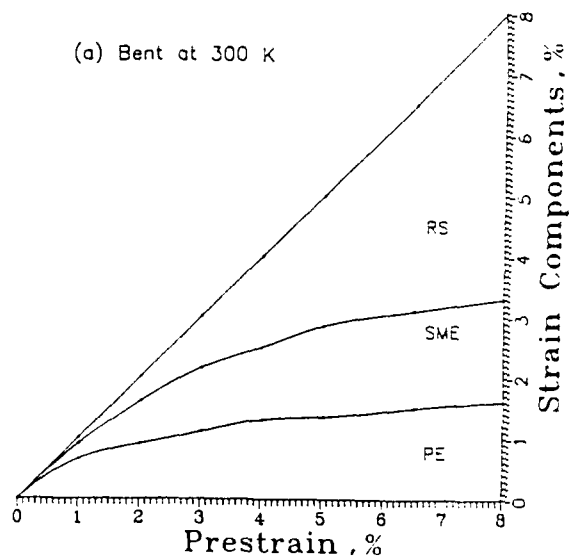
FeMSCN Transformation Heat



fem1

Figure 5.

Alloy 3



Alloy 8

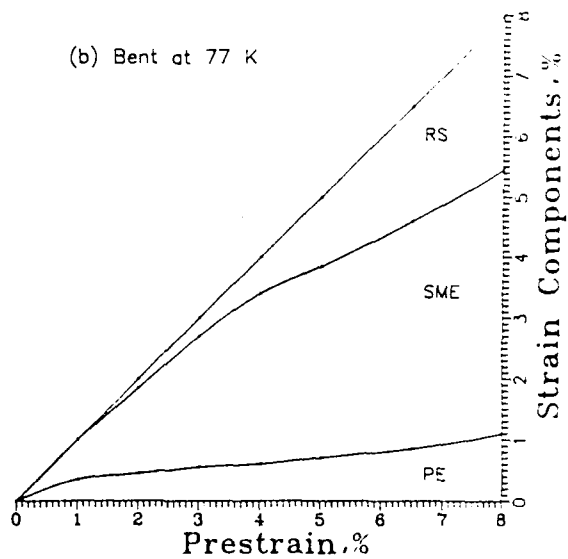
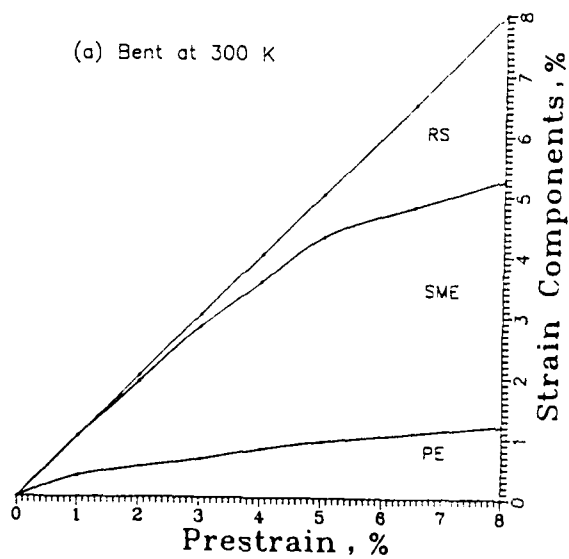
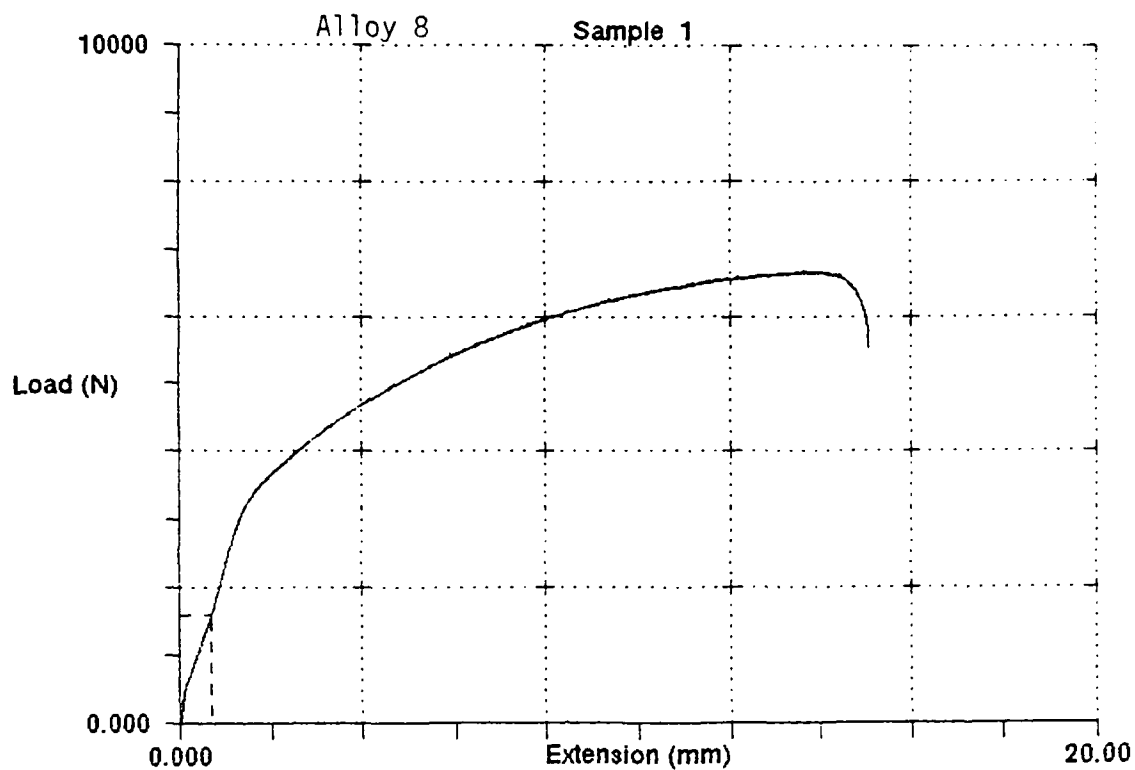


Figure 6.

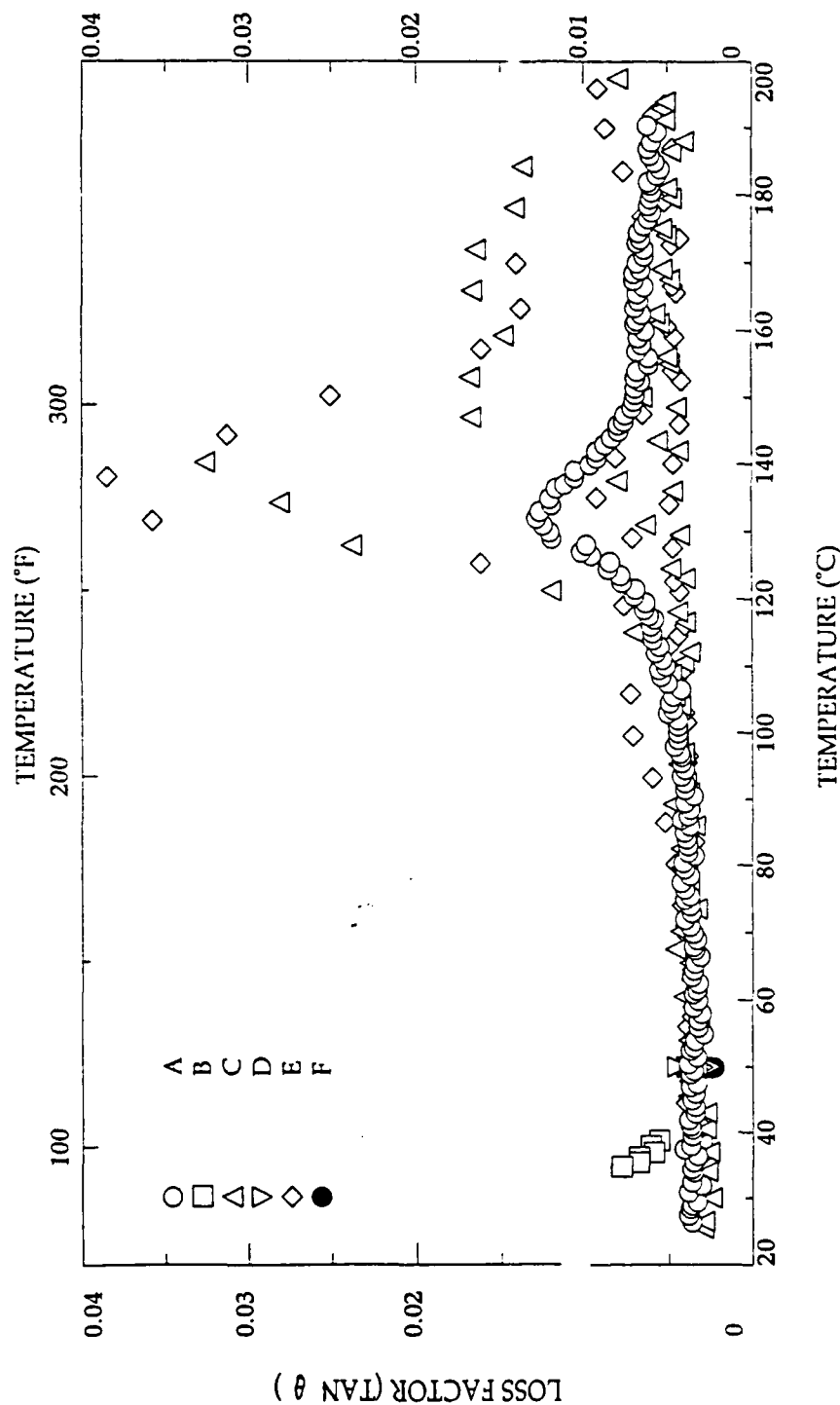


Sample Width (mm)	Sample Breadth (mm)	Gauge Length (mm)	Maximum Load (N)	Load at 3% (N)	Extension @Break (mm)
1.600	5.050	23.00	6725.0	1588.0	15.07

Test Temperature: 50C

Figure 7

MEMRY METALS SAMPLE 1-2A LOSS FACTOR AS A FUNTION OF TEMPERATURE FOR THE FIRST SIX RUNS.



- A) Scanned at 3.5 degC/min from 25 to 200°C.
- B) Measured damping at 35°C for 7 min.
- C) Scanned at 4 degC/min from 25 to 200°C.
- D) Measured damping at 50°C for 1hr.
- E) Scanned at 4 degC/min from 35 to 200°C.
- F) Measured damping at 50°C for 1hr.

Figure 8

MEMRY METALS SAMPLE 1-2A LOSS FACTOR AS A FUNCTION OF
STRAIN AMPLITUDE AT 50°C AND 1 HZ.

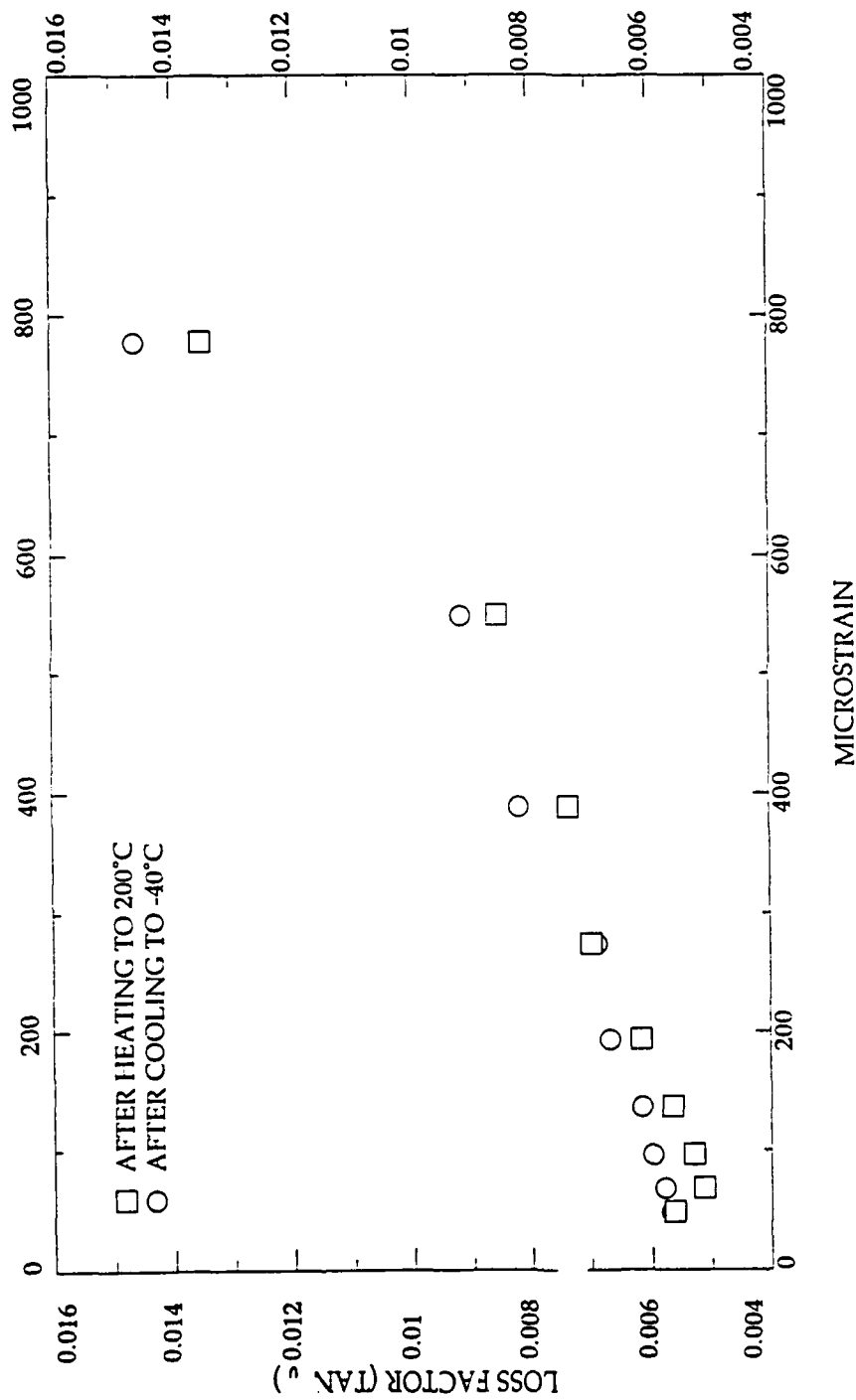


Figure 9.

Table 2.

PROGRAM SCHEDULE **DEVELOPMENT OF HIGH DAMPING FERROUS SMA**

	Assign To	1990				1991				1992			
		I	II	III	IV	I	II	III	IV	I	II	III	IV
Fe-Mn-Si-Ni-Cr Transformation Characterization Mechanical Testing SMA Testing Damping Testing Microstructural Characterization	MT												
	MT												
	MT												
	UM												
	UI												
Fe-Ni-Ti-Co Alloy Preparations (I) Alloy Preparations (II) Transformation Characterization Mechanical Testing SMA Testing Damping Testing Microstructural Characterization	UI												
	MT												
	MT/UI												
	MT/UI												
	MT/UI												
	UM												
	UI												
New Alloy Alloy Development Alloy Preparation Transformation Characterization Mechanical Testing SMA Testing Damping Testing Microstructural Characterization	UI												
	MT												
	MT/UI												
	MT/UI												
	MT/UI												
	UM												
	UI												

MT=Memry Technologies, Inc. (Dr. M.H. Wu)

UI=University of Illinois (Prof. C.M. Wayman)

UM=University of Maryland (Prof. M. Wuttig)